EXECUTIVE SUMMARY

This report presents the results of the remedial investigation (RI) for the Portland Harbor Superfund Site (Site). Portland Harbor encompasses the downstream portion of the lower Willamette River from river mile (RM) 1.9 to RM 11.8. The downstream reach extends from RM 0 to 1.9, the downtown reach extends from RM 11.8 to 15.3, and the upriver reach extends from RM 15.8 to 26. This RI report evaluates the environmental data collected and compiled since the inception of the Portland Harbor Remedial Investigation and Feasibility Study (RI/FS) in 2001. The Lower Willamette Group (LWG) is performing the RI/FS for the Site pursuant to a U.S. Environmental Protection Agency (EPA) Administrative Settlement Agreement and Order on Consent for Remedial Investigation/Feasibility Study (AOC; EPA 2001a, 2003b, 2006a). Oversight of the Portland Harbor RI and FS is being provided by EPA with support from Oregon Department of Environmental Quality (DEQ).

The Willamette River is the 13th largest river in the contiguous United States, with substantial flows, averaging 33,000 cubic feet per second. Flows vary considerably by season, with the lowest flows occurring during the late-summer dry season and typically increasing by a factor of 10 through the winter rainy season. River flows are regulated to some degree by a series of upstream dams, although major floods of 200,000 cubic feet per second or more still occur every few years during large storms. Despite periodic scouring of some locations by floods, the Study Area is situated in a relatively low energy, depositional reach. Although Portland Harbor is over 100 miles from the Pacific Ocean, it is influenced by tides. Tides cause the river stage to rise and fall up to several feet through a tidal cycle. During the dry season, when river discharge is low, rising tides can cause intermittent flow reversals throughout the harbor.

Portland Harbor is located within a region characterized by commercial, residential, recreational, and agricultural uses. Land use along the Willamette River within the harbor includes marine terminals, manufacturing facilities, and commercial operations, as well as public facilities, parks, and open spaces. Historical and current commercial and industrial activities occurring along Portland Harbor include ship building, dismantling, and repair; wood manufacturing and treatment; chemical manufacturing and distribution; metal recycling; manufactured gas production; electrical production and distribution; bulk fuel distribution and storage; asphalt manufacturing; steel mill, smelter and foundry operations; and commodity shipping and associated rail yard operations. Additionally, development along Portland Harbor has included installation of and discharges from municipal and non-municipal (private or public) conveyance systems, including sanitary pipes, stormwater systems, and combined outfalls, as well as permitted discharges. Additional activities that may or do occur in the harbor include dredging to maintain the navigation channel, and capping and other remedial activities associated with the Superfund site. The long history of industrial and shipping activities in Portland Harbor, as well as agricultural, industrial, and municipal activities upstream of Portland Harbor, have contributed to chemical contamination of surface water and sediments.

The lower Willamette River, including the Study Area, provides natural areas and associated recreational opportunities. Adults and children use the river for hunting, boating, water skiing, swimming, diving, and other water activities. Recreational and subsistence fishing occurs from boats and from the shoreline. Transients also use the shoreline intermittently as temporarily dwelling space and as a source of food and water. The lower Willamette River and Portland Basin as a whole provide resources of cultural significance to Native peoples. Fish are among the resources most frequently utilized by Tribes in the Portland Basin. Culturally significant species include salmon, lamprey (eels), eulachon (smelt), and sturgeon. Native plants are gathered for food and medical purposes and as raw material for making items like fishing nets. Further, a number of ecological receptors (invertebrates, fishes, birds, amphibians, and mammals, including some protected by the Endangered Species Act [ESA]), use habitats that occur within and along the river. The river also is an important pathway for migration of anadromous fishes.

The Portland Harbor RI was designed as a multi-year program involving multiple rounds of data collection and evaluation. Samples were collected of sediment, surface water, transition zone water (TZW), storm water, and biota (several species and tissue types) for analyses. Numerous surveys and tests were also conducted. Samples were collected between 2001 and 2008, often timed around varying river stages, river flows, and storm events. Upon completion of data collection, a Data Quality Assessment (DQA) was conducted to determine whether the data were of adequate quality and quantity to support the decision-making process.

Physical System

Portland Harbor occupies the last 12 miles of the Willamette River just above its confluence with the Columbia River. It is the widest portion of the river, and overall acts as a depositional environment for sediments that enter the reach from upstream. Sediments need to be periodically dredged from portions of the navigation channel and berthing areas to allow marine operations. In some locations, sediments may also be re-suspended and move downstream during periods of high flow such as flood events. Re-suspension of sediments can also result from disturbances caused by ships operating within the harbor and by other in-water activities.

The degree of deposition and movement of sediments is controlled largely by the texture and grain size of the sediments, water velocity, and human activities. Once in suspension, finer-grained sediments, including clays and silts, are characteristically transported farther than larger sandy sediments under all flow conditions.

Measured bathymetric changes from 2002 to 2009 indicate the greatest net sediment accumulation from deposition on the river bottom occurs in the channel where the river is wide and where flow velocities are reduced, primarily in the relatively wide reaches from RM 7 to 10 and RM 2 to 5. These areas exhibit relatively high percentages of silt and clay sized particles. Some natural scour areas and slip and berthing areas that have been dredged were also evident in the bathymetric change data. Sediments In these areas are relatively stable during low flow conditions, but may be eroded when exposed to unusually high flow velocities.

Near shore areas between the channel edge and riverbank, and off-channel areas, such as Swan Island Lagoon, Willamette Cove, and port terminals, do not show much net sediment accumulation. Evidence of sediment scour in some portions of these areas appears to be due to bottom disturbance by ship traffic (wakes and prop wash) and possibly other human activities. These factors also appear to mix surface sediments without resulting in net erosion or deposition.

Groundwater

Groundwater flow adjacent to the Study Area is generally toward the river and in the absence of preferential pathways, will be diffuse along the length of the interface of each flow system with the river. Low river stages expose zones of focused discharge as seeps along the bank, where the shallow groundwater surface intersects the ground surface. Preferential pathways focus groundwater flow, particularly where they occur in predominantly fine-grained sediment sequences in the shallow groundwater system. The majority of discharge to the river generally occurs where these preferential pathways intersect the riverbank.

Transition Zone Water (TZW)

The groundwater/surface water transition zone is the interval where both groundwater and surface water comprise some percentage of the water occupying pore space in the sediments. The depth and degree of mixing is anticipated to be relatively small in shallow river sediments, and groundwater likely comprises a greater percentage of the water in the shallower water bioactive zone.

Sediment

The results of sediment sampling display a large variety of sediment types, ranging from sandy gravel to mud, although the majority of the sediments are sands or muddy sands, consistent with the most common sediment types found in the lower Willamette River. As a result of the river widening as it enters the Study Area, the sediment type changes from sand at the upstream end, through muddy sand to sandy mud in the main part of the Study Area. Exceptions to this are pure mud samples in Swan Island Lagoon, and coarser sediments found near the center of the river downstream of Swan Island.

Riverbanks

The majority of the Study Area is industrialized, with modified shoreline and nearshore areas. Wharfs and piers extend out toward the channel, and bulkheads and riprap revetments armor portions of the riverbank. Active dredging has produced a uniform channel with little habitat diversity. However, some segments of the Study Area are more complex, with small embayments, shallow water areas, gently sloped beaches, localized small wood accumulations, and less shoreline development, providing habitat for a suite of local fauna. Types of riverbanks present in the Study Area are expected to influence aquatic and aquatic-dependent or semi-aquatic species occurrence and use of a given area. The most common bank types occurring in the Study Area are riprap, sandy and rocky beach, unclassified fill, and seawall. Critical habitat has been designated for four species of salmon and steelhead and proposed for one species by National Marine Fisheries Service (NFMS) in the lower Willamette River.

Surface Water

The deep open water provides foraging habitat for fish and wildlife that feed in the water column and three types of benthic habitats. Piers and other structures in the open water provide additional habitat for certain species. Shallow-water habitats provide refuge for juvenile salmon and other fishes, as well as greater foraging opportunities for birds and mammals.

Contaminants in the System

Historical sources have released contaminants to the river in the past, but no longer have an upland source to control. Historical releases likely contributed to the majority of the observed chemical distribution in sediments within the Study Area. Many of the historical direct discharges were combined flows of stormwater, industrial wastewater, and sanitary wastewater. Additionally, waste disposal in upland pits, lagoons, or lakes were directly discharged to the river through pipes, ditches, and creeks. Releases were known to have occurred through DEQ investigations at 86 upland sites, generally located within 0.5 mile of the lower Willamette River between RM 2 and 11. Some of the most significant current sources are the result of historic commercial operations, waste disposal, spills and leaks that contaminated soil, groundwater, or the banks that continue to be released to the Site. Contaminants released from sources to media such as air, soil, ground water, surface water, or impervious surfaces may migrate to the lower Willamette River via direct discharge through conveyance systems, overland transport, groundwater flow, riverbank erosion or leaching, atmospheric deposition, overwater activities, and via transport from the upstream watershed.

The Study Area is at the downstream end of a large basin with a long history of industrial, municipal, and agricultural inputs. Agricultural runoff and discharges from other industries and cities upstream as well as point and nonpoint discharges within the Willamette River Basin are potential historical and current sources of contamination in sediment, surface water, and biota in the Study Area. Both point sources and nonpoint sources of contamination are present above Willamette Falls in the Upper Willamette River. Agriculture, forestry, urban land use, geologic features, and atmospheric deposition may have contributed to conditions in Portland Harbor.

Contaminant Distribution

Sediment contaminant concentrations are greatest in localized nearshore and off-channel areas as compared to sediments in the navigation channel, Multnomah Channel, and downstream areas. Concentrations of total PCBs, DDx, total PAHs, hexachlorobenzene, total chlordanes, aldrin and dieldrin, gamma-hexachlorocyclohexane (Lindane), lead, and TBT are generally higher in deeper sediments than in the surface layer, indicating that past contaminant inputs were greater than current inputs. The few exceptions include areas where higher surface sediment concentrations appear to be associated with ongoing sources, low rates of clean sediment deposition, or physical disturbance of surface sediments exposing contaminated subsurface sediment (for example, prop scour).

Contaminants that may be derived predominantly from regional or upstream inputs show widespread surface sediment distributions without distinct, isolated areas of higher concentrations. A number of contaminants exhibit relatively high sediment concentrations in distinct areas offshore of known or likely sources. These areas are separated by large areas with relatively lower concentrations lacking obvious concentration gradients. Contaminants that exhibit this trend include total PCBs, PCDD/Fs, BEHP, butylbenzyl phthalate, DDx, total PAHs, pentachlorophenol, hexachlorobenzene, total chlordanes, Lindane, copper, zinc, and TBT.

Several locations within the Study Area exhibit relatively high surface sediment concentrations of more than one contaminant:

- **RM 11E:** total PCBs, dioxins/furans, DDx, chromium, copper
- **RM 9.7W:** total PCBs, dioxins/furans, BEHP, zinc
- **RM 8.7–9.3W:** total PCBs, dioxin/furans, total PAHs, total chlordanes, copper, mercury, nickel, and zinc
- **RM 8.3W:** total PCBs, total PAHs, BEHP, total chlordanes, dieldrin, lead, copper
- **Swan Island Lagoon:** total PCBs, dioxins/furans, total PAHs, BEHP, total chlordanes, chromium, copper, zinc, TBT
- **RM 6.8–7.5W:** dioxins/furans, DDx
- **RM 6.7–6.8E:** total PCBs, dioxins/furans, copper
- **RM 5.6–5.7E:** dioxins/furans, total PAHs, total chlordanes, Lindane, chromium, copper, lead, mercury, zinc,

Indicator Contaminants (ICs)

Due to the large number of contaminants detected at the Site in various media, a subset of the contaminants is selected as indicator contaminants to facilitate the presentation of the distribution of contamination in the Study Area. The selected ICs include:

- total polychlorinated biphenyls (PCBs)
- total polychlorinated dibenzo-p-dioxin/furans (PCDD/Fs
- total DDx (sum of 2,4- and 4,4- dichlorodiphenyltrichloroethane [DDT], dichlorodiphenyldichloroethane [DDD] and dichlorodiphenyldichloroethene [DDE])
- total polycyclic aromatic hydrocarbons (PAHs)
- bis(2-ethylhexyl)phthalate (BEHP)
- total chlordanes
- aldrin
- dieldrin
- arsenic
- chromium
- copper
- zinc
- tributyltin (TBT)

Contaminant Loading

External contaminant loads to the Study Area include upstream loading via surface water and sediment bedload, stormwater, permitted industrial discharges, upland groundwater transport, atmospheric deposition, upland soil and riverbank erosion, groundwater advection through subsurface sediments, and overwater releases. Historical contaminant loading is reasonably expected to have occurred by all of the loading mechanisms discussed above and the historical load may be significantly greater than current load due to changes in regulations and reduction or elimination of chemical use in the Study Area and Willamette Basin. The primary current mechanisms for riverbank erosion are river water moving over bank materials; direct overland transport across these materials; and erosion of bank material into the river.

Current and historical loading of select contaminants to the surface sediment and surface water of the Study Area by external loading mechanisms was estimated. Loads for all of the contaminants are generally higher on a daily basis during high flows than during low flows. The particulate fraction represents the larger component for PCBs, PCDD/Fs, DDx, pesticides, and metals. The dissolved fraction is the larger component for low molecular-weight PAHs (LPAHs), non-DDx pesticides, and hexachlorobenzene. In general, the ratios of particulate to dissolved mass loading for all surface water loading contaminants do not show large or consistent variations under different flow conditions, indicating possible conditions of equilibrium or near equilibrium.

Modeling was performed to predict sediment loads entering the Study Area over a range of flow conditions. The net flux of suspended sediment for all flow regimes modeled is positive, indicating that the harbor is generally a trap for material entering from upstream. However, various areas within the Study Area may be largely depositional, erosional, or subject to both processes. Stormwater loading to the Study Area was also calculated for select contaminants using stormwater and outfall sediment trap data. Loads to the Study Area are calculated based on composite water and sediment trap data collected from heavy industrial, light industrial, residential, parks/open space, major transportation, and non-representative locations (locations not included in the other five land uses). Estimated stormwater loads for non-DDx pesticides and BEHP are typically higher than the sediment trap estimated loads, while estimated stormwater loads for total PCBs and metals are slightly higher than the estimated sediment trap loads. Estimated stormwater loads for total DDx, total PAHs, and hexachlorobenzene are generally within the range of loads calculated from the sediment trap data. The estimated load for each of these contaminants is highest for the heavy industrial land use.

Contaminant Fate and Transport

Physical, chemical, and biological processes influence the fate and transport of contaminants within the in-water portion of the Study Area. Fate and transport processes in sediment and TZW include distribution between the solid and aqueous phases, degradation and transformation processes (hydrolysis, dehalogenation, biodegradation, oxidation, and reduction, and physical transport processes resulting from natural and anthropogenic forces. Sediment movement into, within, and through the Study Area occurs as suspended load in the water column and as bedload along the riverbed. Fate and transport processes for contaminants present in the dissolved phase and sorbed to suspended solids in surface water include partitioning between surface water, air, and suspended sediment, physical transport of surface water and suspended solids via advection, and physiochemical and biological processes.

Organisms living in the lower Willamette River take up contaminants through physical, chemical, and biological processes and can modify the contaminant burden in their tissues through growth, reproduction, excretion, metabolic transformation, or sequestration. Some chemicals are transferred among organisms through trophic interactions, resulting in increases in concentrations of some contaminants at higher trophic levels. When sediment or prey is ingested by organisms and contaminants are absorbed, the contaminants may undergo various metabolic processes that change the chemical structure and properties. Once absorbed, metals not excreted may be stored in calcium carbonate matrices or bone, which tend to reduce the reactivity of the metal. Hydrophobic organic contaminants that are not metabolized tend to be stored in organs or fatty tissues. These stores can be released within the aquatic and terrestrial food webs when these organisms are consumed by others, upon their death and decomposition, or by transfer to their offspring.

Background Concentrations

Contaminant concentrations may be due to releases from the Site itself, as well as natural and/or anthropogenic sources that are not Site-related. An understanding of background conditions are important at Portland Harbor because of the urbanized and industrialized setting, and the fact that the lower portion of the river is influenced by many human activities occurring upstream and throughout the watershed. Thus, Site-specific background concentrations can be develop remedial goals and characterize risk from concentrations that may be attributed to background sources. The upriver reach of the lower Willamette River extending from RM 15.3 to 28.4 was selected as the reference area for determining background sediment concentrations. The area is representative of the urban and suburban upland conditions along the banks of the lower Willamette River as it flows into Portland through its suburbs, but is upstream and uninfluenced by releases from the Portland Harbor Study Area. For the RI, background concentrations were calculated for arsenic, total chlordane, chromium, copper, DDx, BEHP, mercury, total PAHs, PCBs as Aroclors, PCBs as congeners, total PCDD/Fs, and zinc. Background concentrations were not extablished for aldrin and dieldrin due to their infrequent detection in the upstream reach data set. A background concentration was not established for TBT due to the limited number of detections in the upstream reach.

Human and Ecological Risk Assessments

The baseline human health risk assessment evaluated potential exposure to contaminants in sediment and estimated cancer risks and noncancer hazards in the absence of remedial actions or institutional controls.

Current or potentially exposed populations were identified based on consideration of both current and potential future uses of the Study Area. Currently or potentially exposed populations were identified based on consideration of both current and potential future uses of the Study Area, and include populations who may be exposed to contamination though a variety of activities. The specific populations and exposure pathways evaluated were:

- Dockside workers — direct exposure via incidental ingestion and dermal contact with beach sediments.
- In-water workers — direct exposures to in-water sediment.
- Transients — direct exposure to beach sediment, surface water for bathing and drinking water scenarios, and groundwater seeps.

- Recreational beach users — direct exposure to beach sediment and surface water while for swimming.
- Tribal fishers — direct exposure to beach or in-water sediments, and consumption of migratory and resident fish.
- Recreational and subsistence fishers — direct exposure to beach or in-water sediments, consumption of resident fish, and consumption of shellfish.
- Divers — direct exposure to in-water sediment and surface water.
- Domestic water use — direct exposure to untreated surface water potentially used as a drinking water source in the future.
- Exposure to persistent bioaccumulative contaminants via breastfeeding.

Exposures were evaluated on a Study Area-wide basis, as well as on more localized spatial scales as appropriate for each exposure scenario. The exposure assessment evaluated a reasonable maximum exposure (RME) and the central tendency (CT). Exposure point concentrations (EPCs) were calculated to represent the average concentration contacted over the duration of the exposure. Information from the exposure assessment and toxicity assessment was integrated to assess both carcinogenic and non-cancer effects in the risk characterization. Contaminants are identified as posing unacceptable risks if they result in a cancer risk greater than 1×10^{-6} or a hazard quotient (HQ) greater than 1.

The major findings of the BHHRA are:

- Estimated cancer risks resulting from the consumption of fish or shellfish are generally orders of magnitude higher than risk resulting from direct contact with sediment and surface water. Risks and noncancer hazards from fish and shellfish consumption exceed the EPA point of departure for cancer risk of 1×10^{-4} and target hazard index (HI) of 1 when evaluated on a harbor-wide basis, and when evaluated on the smaller spatial scale by river mile. Consumption of resident fish species consistently results in the greatest risk estimates. Evaluated harbor-wide, the estimated RME cancer risks are 4×10^{-3} and 1×10^{-2} for recreational and subsistence fishers, respectively.

- Noncancer hazard estimates for consumption of resident fish species are greater than 1 at all river miles. Based on a harbor-wide evaluation of noncancer risk, the estimated RME HI is 300 and 1,000 for recreational and subsistence fisher, respectively. The highest hazard estimates for recreational fishers are at RM 4, RM 7, RM 11, and in Swan Island Lagoon.

  The highest noncancer hazards are associated with nursing infants of mothers, who consume resident fish from Portland Harbor. When fish consumption is evaluated on a harbor-wide basis, the estimated RME HI is 4,000 and 10,000 for breastfed infants of recreational and subsistence fishers, respectively. Evaluated on a harbor-wide scale, the estimated RME HI for tribal consumers of migratory and resident fish is 600 assuming fillet-only consumption, and 800 assuming whole-body consumption. The corresponding HI estimates for nursing infants of mothers, who consume fish, are 8,000 and 9,000 respectively, assuming maternal consumption of fillet or whole-body fish.

- PCBs are the primary contributor to risk from fish consumption harbor-wide. When evaluated on a river mile scale, dioxins/furans are a secondary contributor to the overall risk and hazard estimates, particularly at RM 6 and 7. PCBs are the primary contributors to the noncancer hazard to nursing infants, primarily because of the bioaccumulative properties of PCBs and the susceptibility of infants to the developmental effects associated with exposure to PCBs.

The following complete and significant exposure pathways were quantitatively evaluated in the BERA using multiple lines of evidence:

- **Benthic invertebrates –** Direct contact with sediment and surface water, ingestion of biota and sediment, and direct contact with shallow TZW
- **Fish –** Direct contact with surface water, direct contact with sediment (for benthic fish receptors), ingestion of biota, incidental ingestion of sediment, and direct contact with shallow TZW (for benthic fish receptors)
- **Birds and mammals –** Ingestion of biota and incidental ingestion of sediment
- **Amphibians and aquatic plants –** Direct contact with surface water and shallow TZW.

The following presents the primary conclusions of the BERA.

- In total, 93 contaminants (as individual contaminants, sums, or totals) pose potentially unacceptable ecological risk. The list can be condensed if individual PCB, DDx and PAH compounds or groups are condensed into three comprehensive groups: total PCBs, total DDx, and total PAHs. Doing so reduces the number of contaminants posing potentially unacceptable risks to 66.

- Risks to benthic invertebrates are clustered in 17 benthic areas of concern (AOCs).

- Sediment and TZW samples with the highest HQs for many contaminants also tend to be clustered in areas with the greatest benthic invertebrate toxicity.

- COPCs in sediment that are most commonly spatially associated with locations of potentially unacceptable risk to the benthic community or populations are PAHs and DDx compounds.

- The most ecologically significant contaminants are PCBs, PAHs, dioxins and furans (as toxic equivalent [TEQ]), and DDT and its metabolites. PAHs and DDx risks are largely limited to benthic invertebrates and other sediment-associated receptors. PCBs tend to pose their largest ecological risks to mammals and birds.

- The combined toxicity of dioxins/furans and dioxin-like PCBs, expressed as total TEQ, poses the potential risk of reduced reproductive success in mink, river otter, spotted sandpiper, bald eagle, and osprey. The PCB TEQ fraction of the total TEQ is responsible for the majority of total TEQ exposure, but the total dioxin/furan TEQ fraction also exceeds its TRV in some locations of the Study